Dipole instabilities in IOTA

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Outline

- **Wake field implementation in Synergia**
- **Dipole instabilities in linear lattice**
- **Dipole instabilities with the nonlinear lens**

Space charge forces

- **The space charge solver and the wake implementation are not independent**
- **Force acting on a particle due to the electromagnetic field created by the other particles:**

space charge solver with grounded pipe

resistive wall wake

$$F = F^{\sigma=\infty} + \left(F - F^{\sigma=\infty}\right)$$

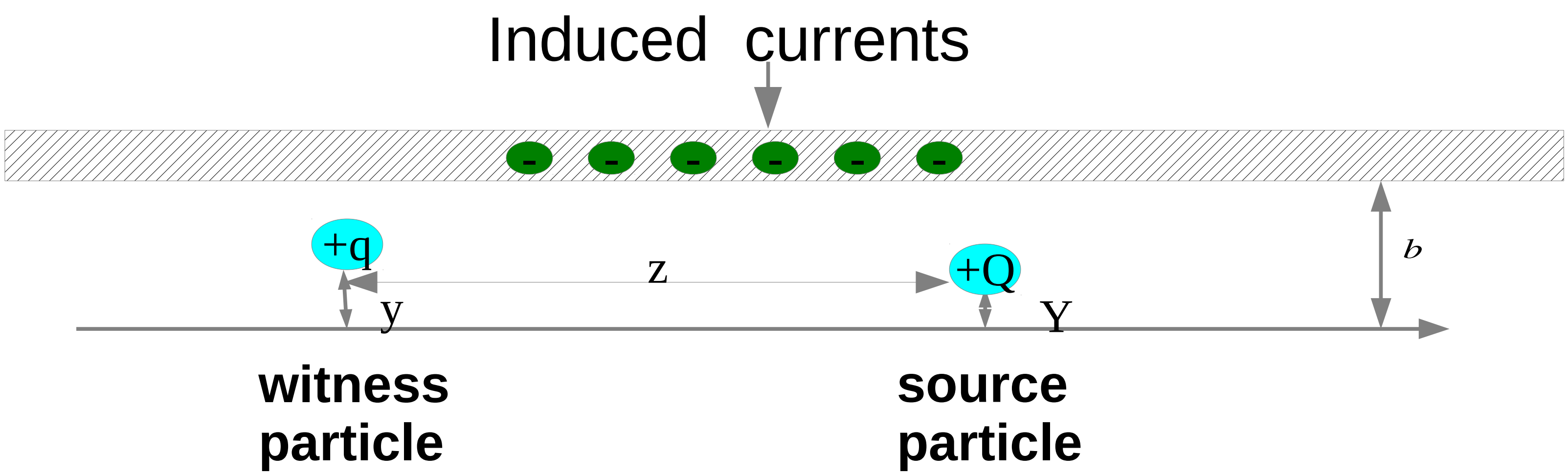
$$F = F^{no\ pipe} + \left(F^{\sigma=\infty} - F^{no\ pipe}\right) + \left(F - F^{\sigma=\infty}\right)$$

space charge solver with open boundary condition

ideal pipe currents

resistive wall wake

Wake fields



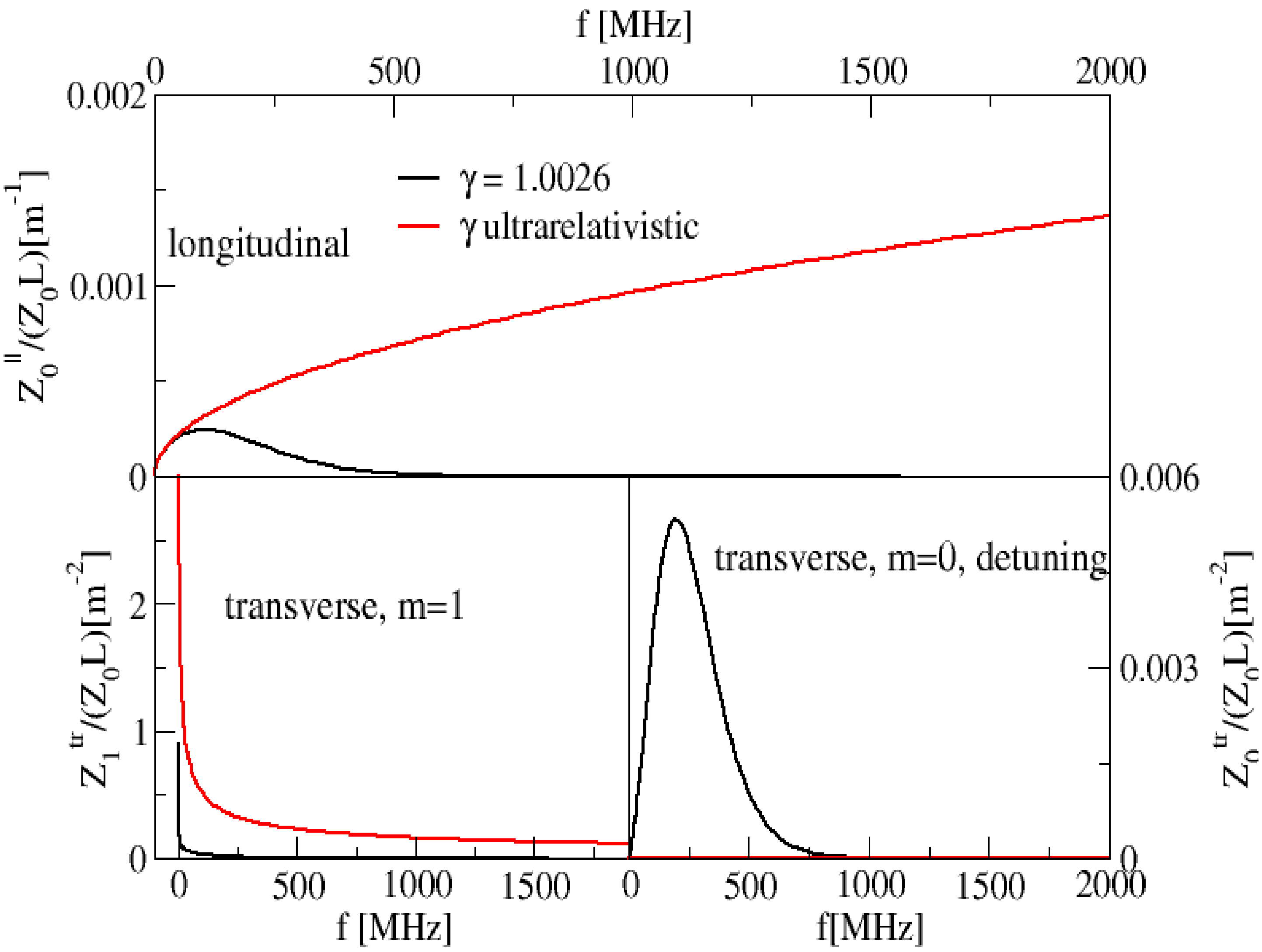
$$\beta c \Delta p_z = -qQW^{\parallel}(z)$$

$$\beta c \Delta p_x = -qQ\left(W_X^{\perp}(z) X + W_x^{\perp}(z) x\right)$$

$$\beta c \Delta p_y = -qQ\left(W_Y^{\perp}(z) Y + W_y^{\perp}(z) y\right)$$

- q,Q - charge of the source and witness particle
- X,Y - displacements of the source particle
- *x,y* - displacements of the witness particle
- *z* - distance between the source and the witness particles

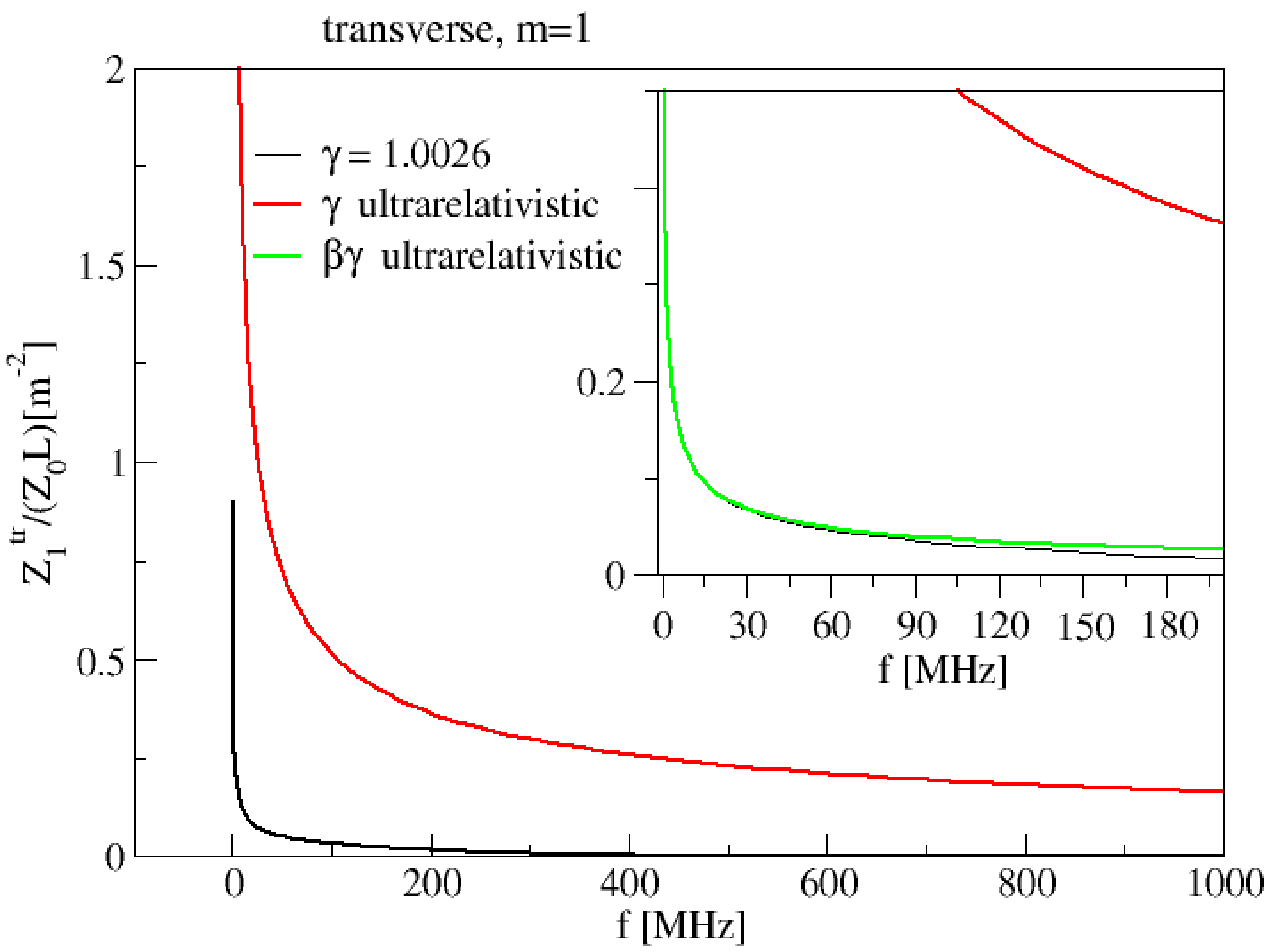
Impedance in IOTA straight sections



- **Low energy beam**
  γ=1.0026
  β=0.0728
- **the high frequency impedance differs significantly from the ultrarelativistic approximation**

A. Macridin, FERMILAB-PUB-12-518-CD

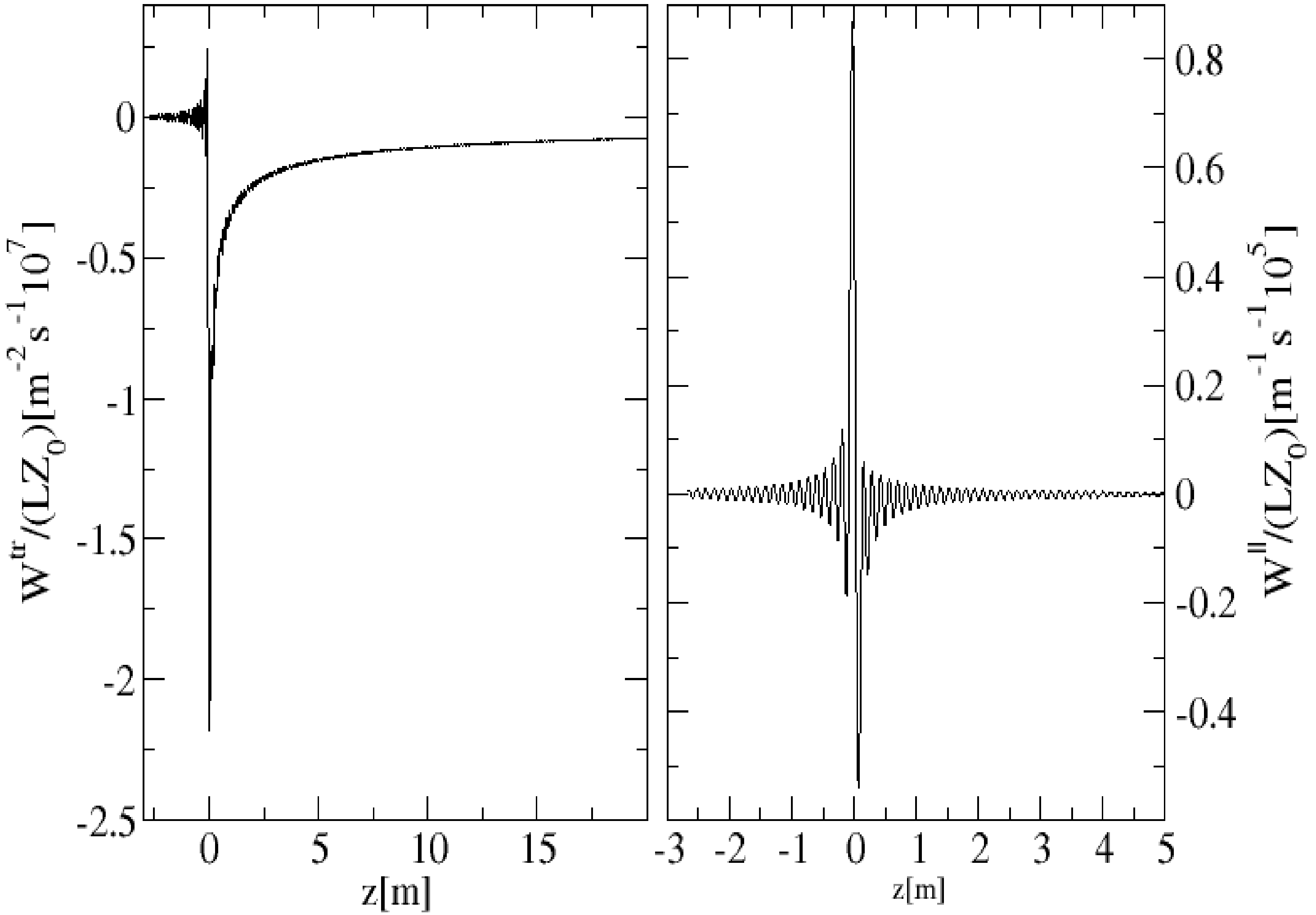
Transverse impedance



- **The transverse impedance is reduced by a factor of β from the ultrarelativistic approximation in the frequency region relevant for instabilities**

A.Burov, V. Lebedev, FERMILAB-CONF-02-100-T

Wake fields



- **Wake fields are small in IOTA**

Coasting beam dipole instabilities

- **The modes are characterized by the wave number *n***

$$D_n(z,t)=\Delta \exp\left(i\frac{2\pi n z}{L}-i\Omega t\right)$$

- **The growth rate is proportional to the real part of impedance**

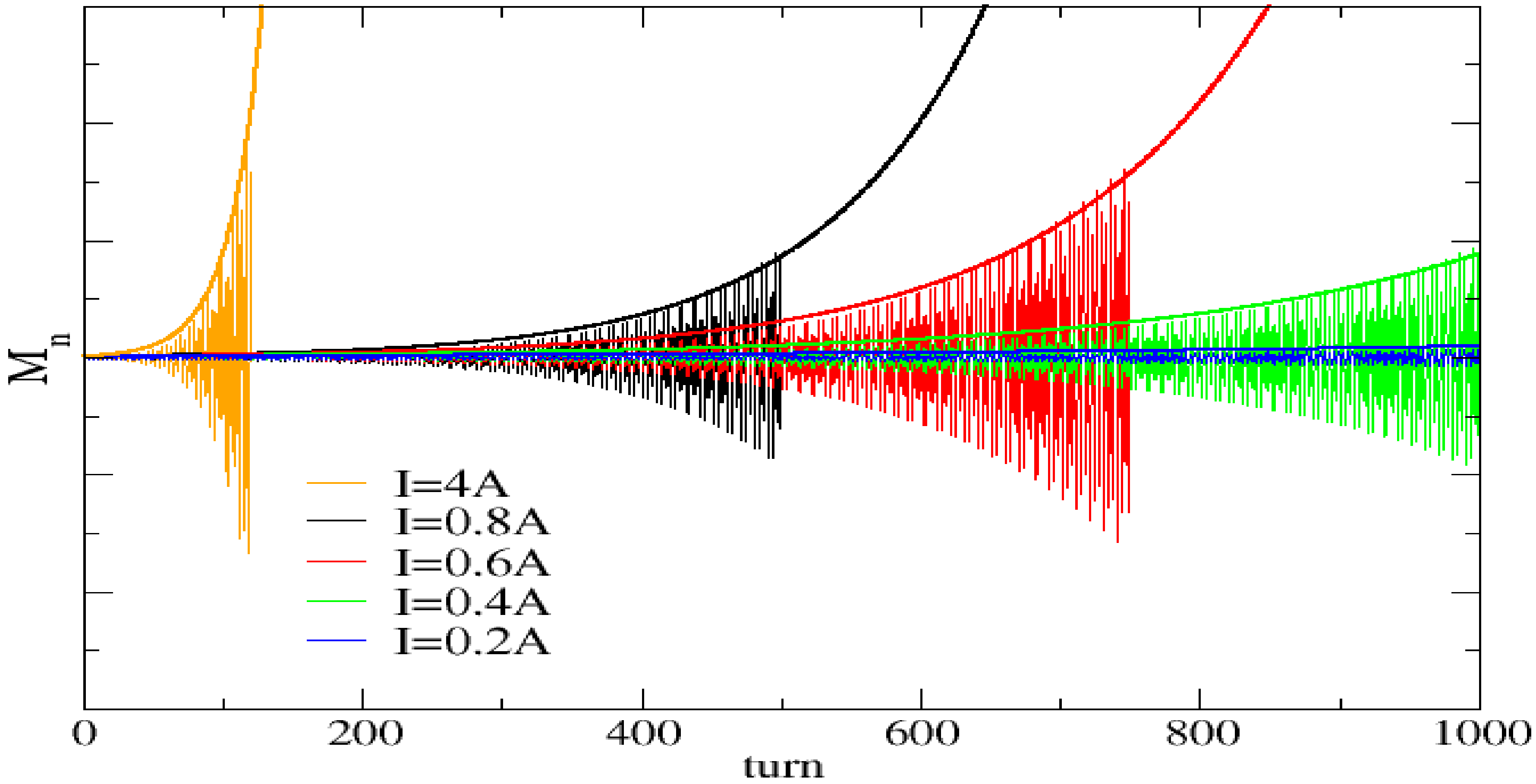
$$\lambda=-\frac{N r_0 c^2}{2\omega_\beta \gamma}\frac{\Re Z^{\perp}(n\omega_0+\omega_\beta)}{L}$$

- **The beam is unstable when $ReZ(n\omega_0+\omega_\beta)<0$, i.e. $n<-\omega_\beta/\omega_0$**

in IOTA case n< -5

n=14

Space charge neglected

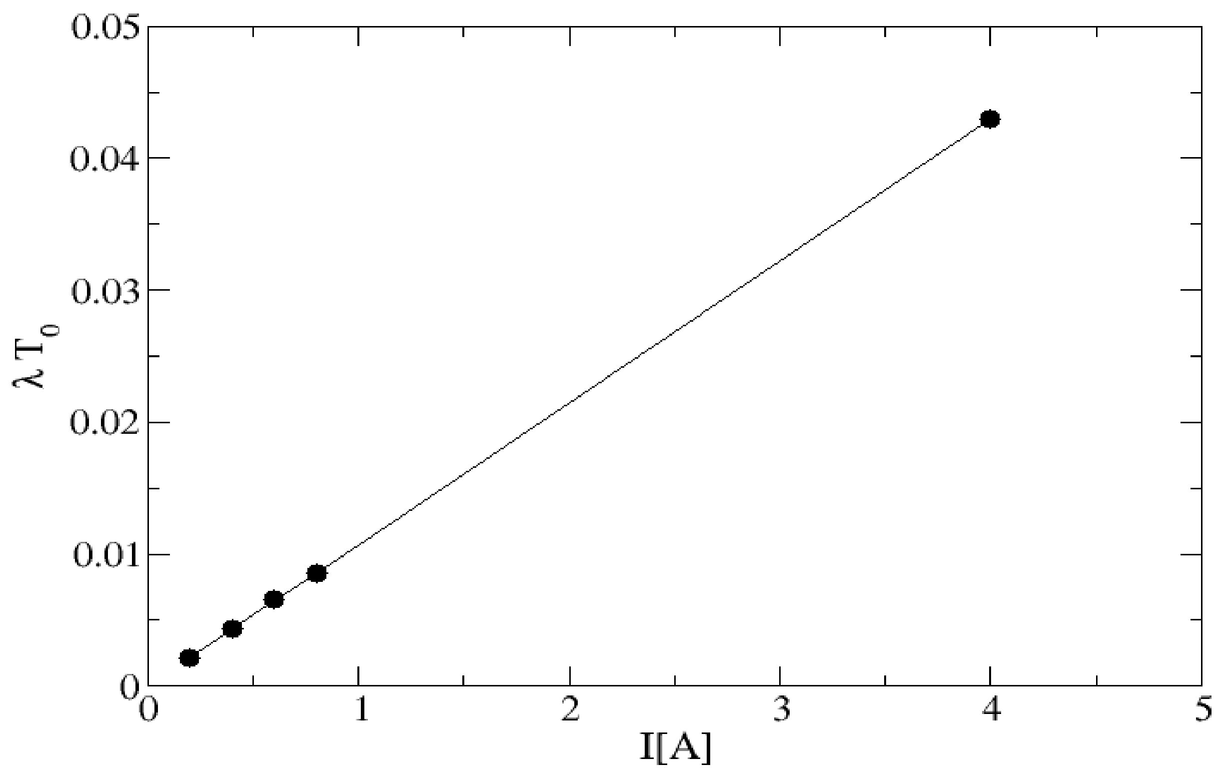


$$D^{meas}(z) = \int x \rho(x, z)\, dx$$

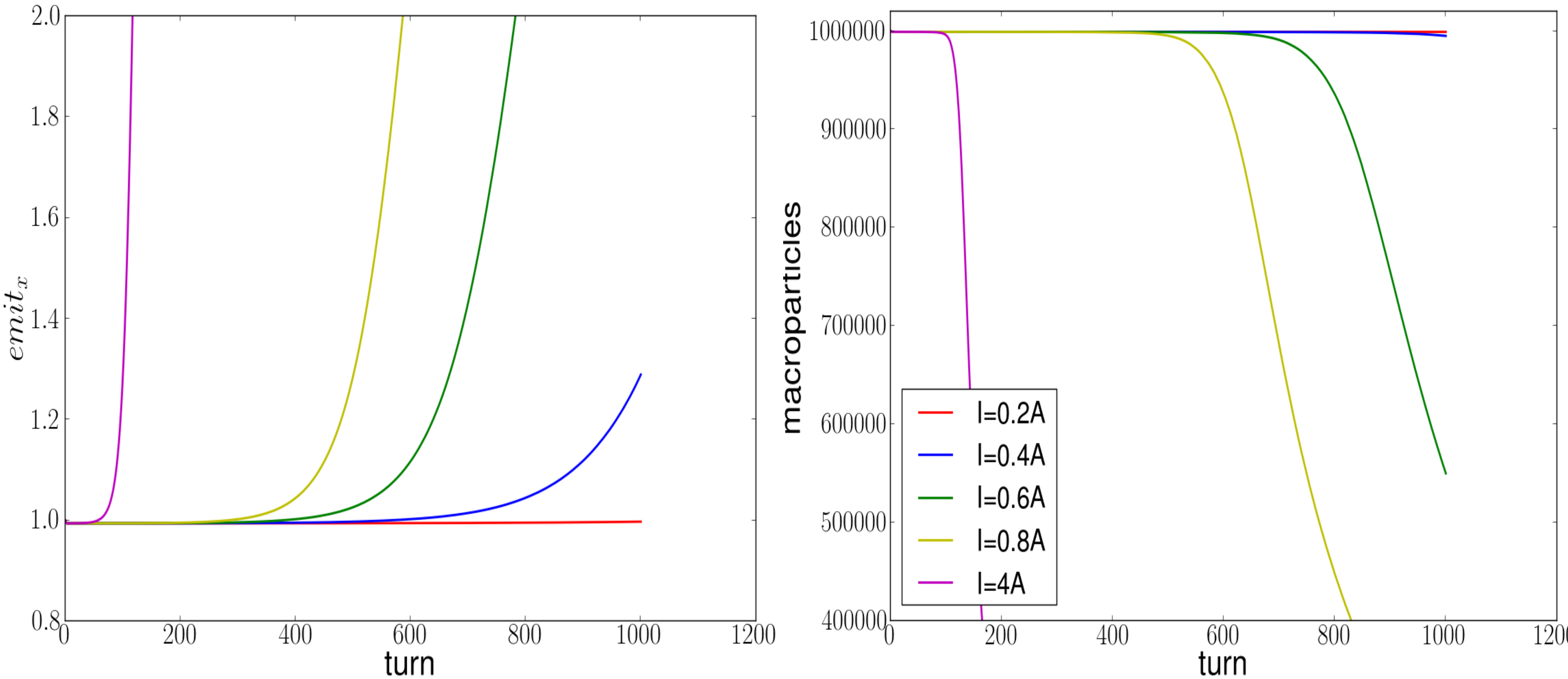
$$M_n(t) = \int_0^L D^{meas}(z, t) \cos\left(2\pi n \frac{z}{L}\right) dz$$

Typical I =0.008A

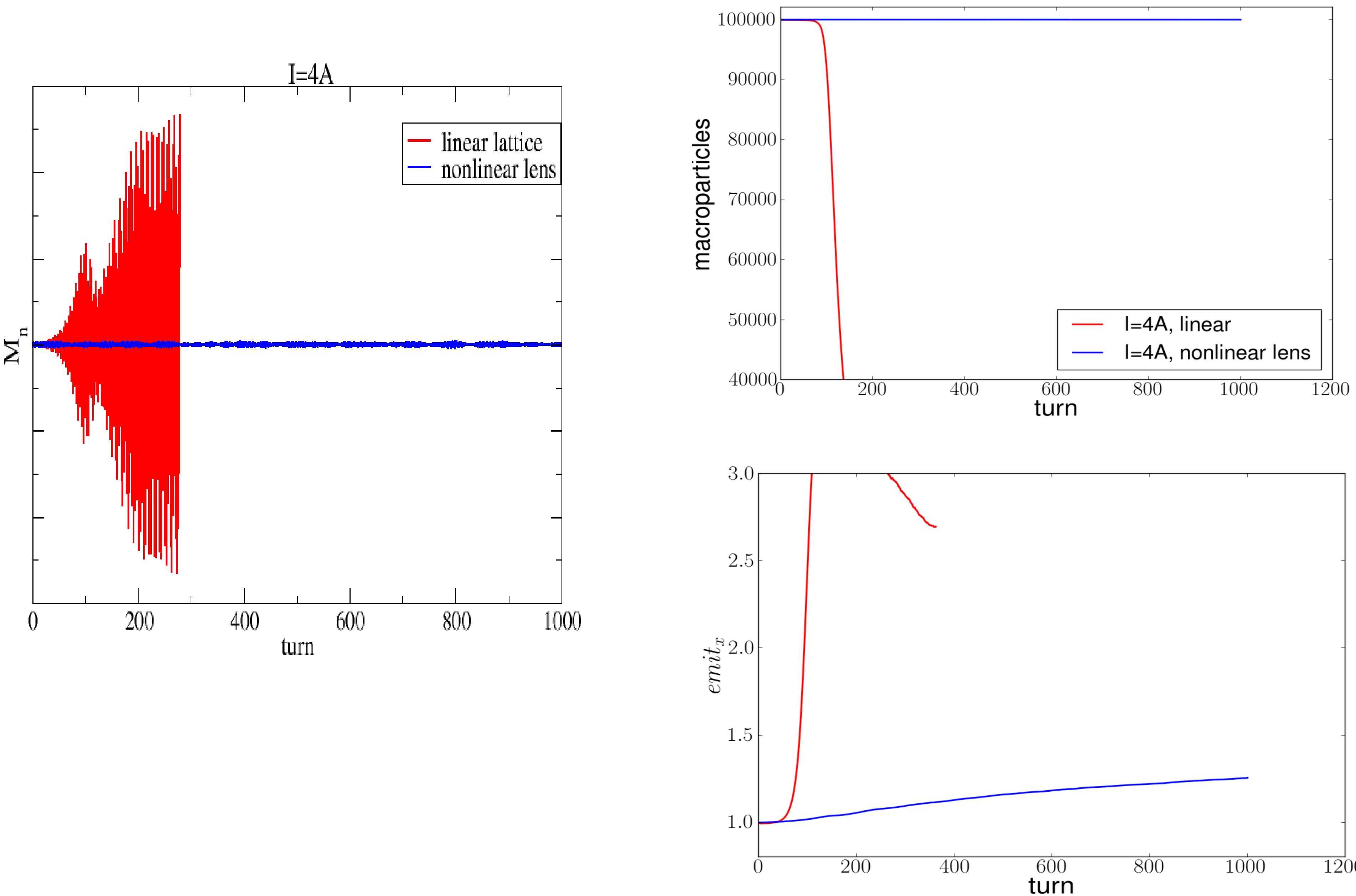
Growing rate vs intensity



Instability can be seen in the emittance

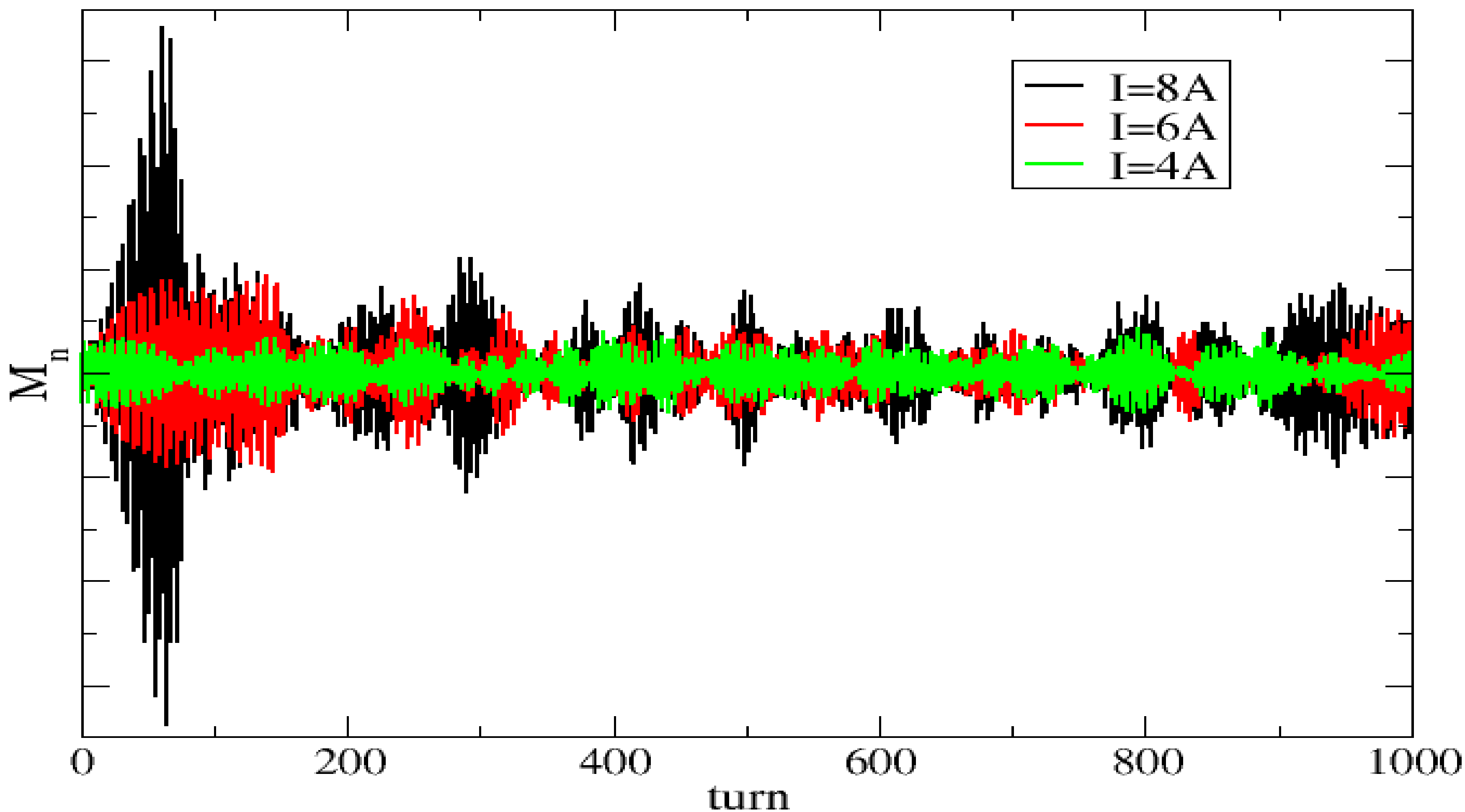


Nonlinear lens stabilizes the beam

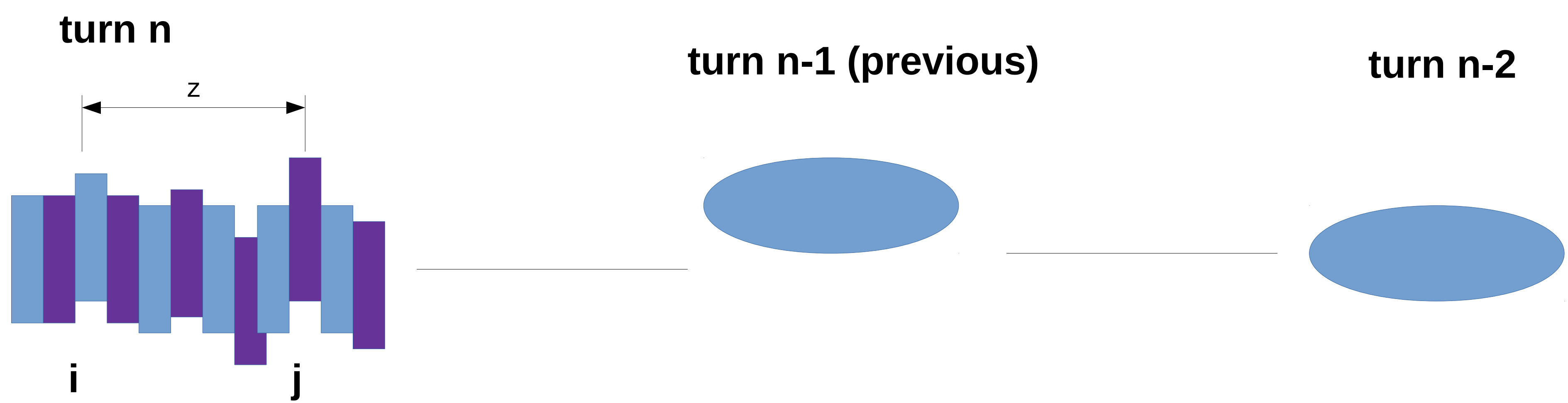


Nonlinear lens

n=14



What is not right?



$$\Delta p_i = W(z_{ji})\bar{X}_j$$

In-bunch wake:
slices

$$\Delta p_i = W(L + \bar{z}_{n-1} - \bar{z}_n)\bar{x}_{n-1}$$

contribution from previous turns:
beam seen as a whole

- **For coasting beams the end and the beginning of the bunch are treated differently**
- **The modes are not commensurate with the lattice and not described by a wave number *n***
- **The simulation is more appropriate for a long beam which does not fill the entire ring**

Conclusions

- **The nonlinear insert strongly stabilize the dipole instabilities induced by the wake field**

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Revolution frequency w0=2 pi beta c/L=3.4MHz, nu0=0.54MHz
Linear lattice rms emittance: ex=ey=5 mm mrad, chroms=-11, -6.85

Nonlinear length rms emittance: ex=2 mm mrad, ey=4.6 mm mrad
Nonlinear tunes: Qx=5.402, Qy=5.134, chroms=-10.9, -9,8

Nonlinear lens